Overview of HHT Processing and the HHT-DPS

HHT Background

Traditional Fourier-based methods are designed to work with linear data, or linear representations of nonlinear data and are not a good method for studying waves and other nonlinear phenomena. Nonlinear applications will require newly emerging data processing tools and algorithms, such as the Hilbert-Huang Transform (HHT).

One of the main heritage processing tools used in scientific data analysis is the Fourier Transform and its digital analogue, the Fast Fourier Transform (FFT). The Fourier Transform (long-time existence) and associated FFTs (fairly recent developments) carry strong ***a-priori*** assumptions about the source data, such as linearity and stationariness. Natural phenomena measurements are essentially nonlinear and nonstationary. The accommodation of this fact in FFT-based analysis often involves using more data samples to assure acceptable convergence and nonalgorithmic procedural steps in the interpretation of FFT results. Wavelet-based analysis may yield some improvement over the FFT because it can handle nonstationary data, but it retains the limitation of requiring the data set to be linear. Wavelet methods may also prove inadequate because, although wavelet is well-suited for analyzing data with gradual frequency changes, its non-locally adaptive approach causes leakage. This leakage can spread frequency energy over a wider range, removing definition from data and giving it an overly smooth appearance. Only recently has an alternative view for mechanics, the Hilbert view, and the associated processing tool, the Empirical Mode Decomposition, been proposed.

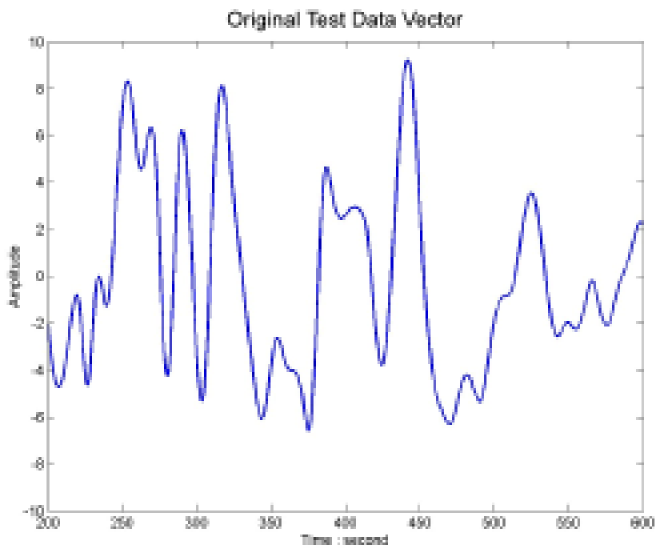
A recent development at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC), known as the Hilbert-Huang Transform (HHT), provides a novel approach to the solution of the nonlinear class of problems previously in the domain of FFT. The HHT method was developed and patented by Dr. Norden Huang of the GSFC Laboratory for Hydrospheric Processes. The HHT allows direct algorithmic analysis of nonlinear and nonstationary data functions by using an engineering and ***a-posteriori*** data processing method, namely an Empirical Mode Decomposition (EMD). Using this method results in the unconstrained decomposition of the source data function into a finite set of Intrinsic Mode Functions (IMFs) that can be completely analyzed by the classical Hilbert Transform, thus making the HHT devoid of the FFT limitations.

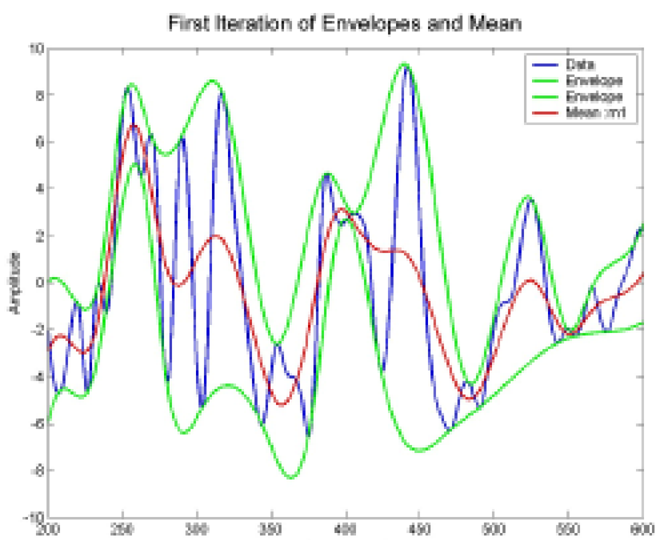
The following sections describe the basic principles behind the HHT method and recent HHT software implementation.

Description of HHT Technology

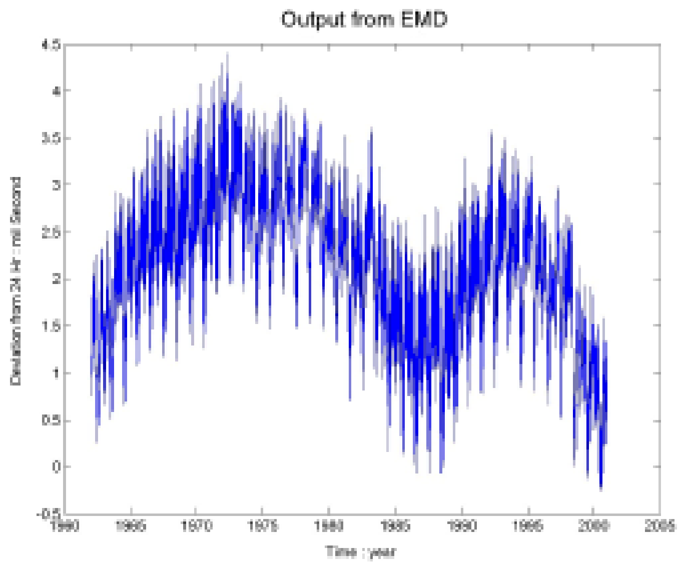
HHT-based processing consists of two main elements: Empirical Mode Decomposition (EMD), and Hilbert spectral analysis. The EMD phase generates the adaptive basis Intrinsic Mode Functions (IMFs) from the data set, and the Hilbert spectral analysis generates a “time-frequency-energy” representation of the data, based on the IMFs.

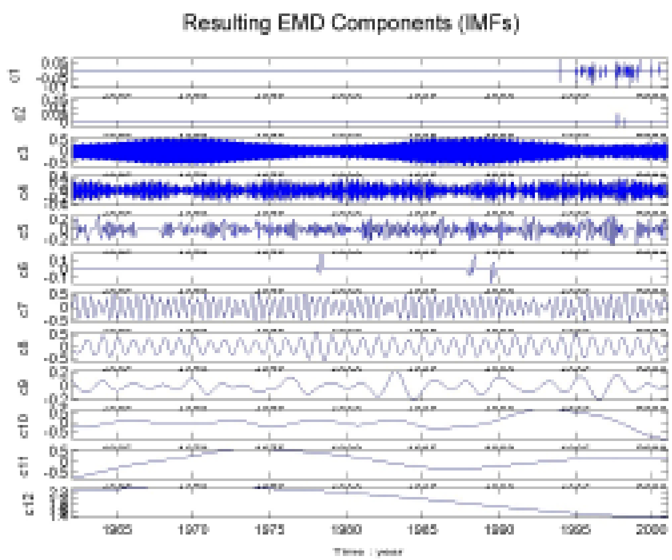
The EMD phase is an iterative process where envelopes and their means are used to break down a data vector into components (IMFs). The figures below show an original data vector and the first iteration of envelope and mean.





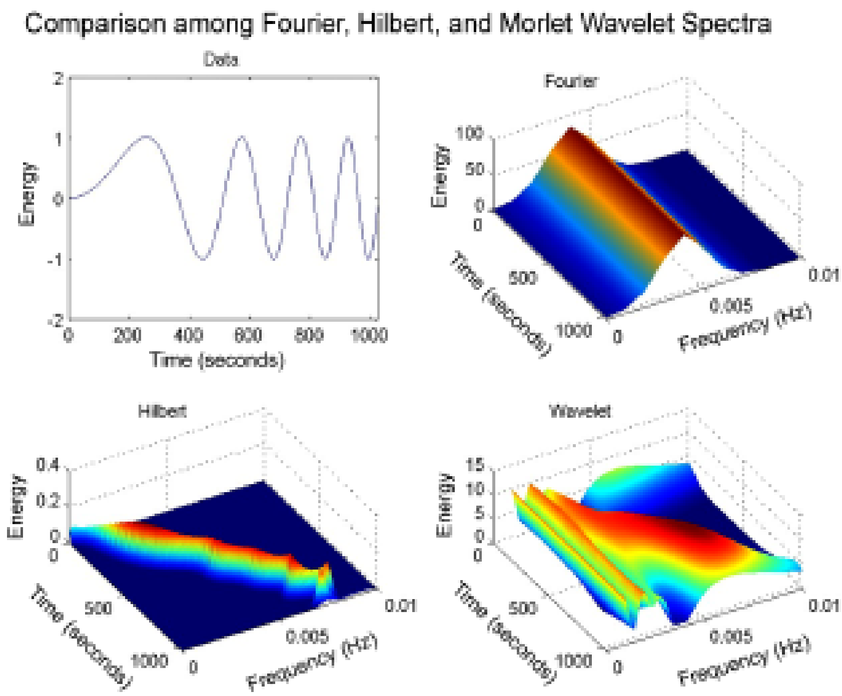
In each iteration, the envelope mean is subtracted from the data signal, and this "sifting" process is repeated until an IMF is obtained. An IMF is defined as any function having the same number of zero crossings and extrema and also having symmetric envelopes defined by local maxima and minima. Once the first IMF is found it is subtracted from the original data signal, and the "sifting" process is initiated on the remaining portion of the signal to determine the second IMF. This sifting and subtracting process continues until an IMF with no more than two extrema is found. The figures below show the results of a typical EMD process.



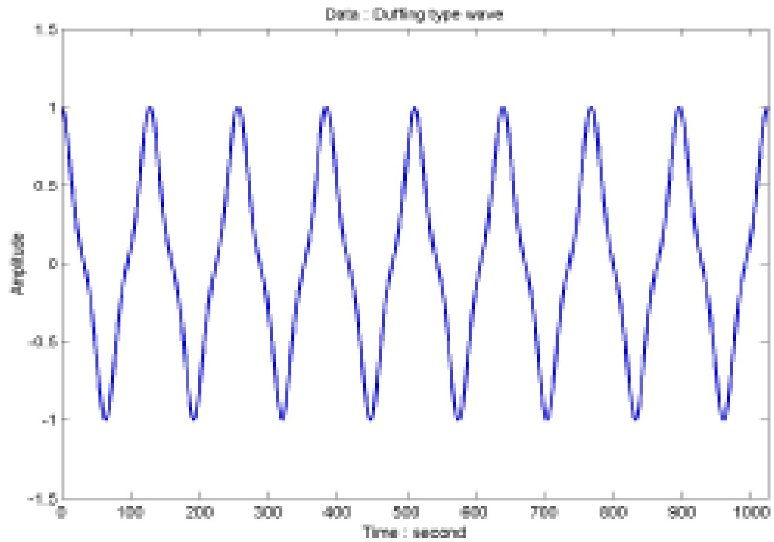


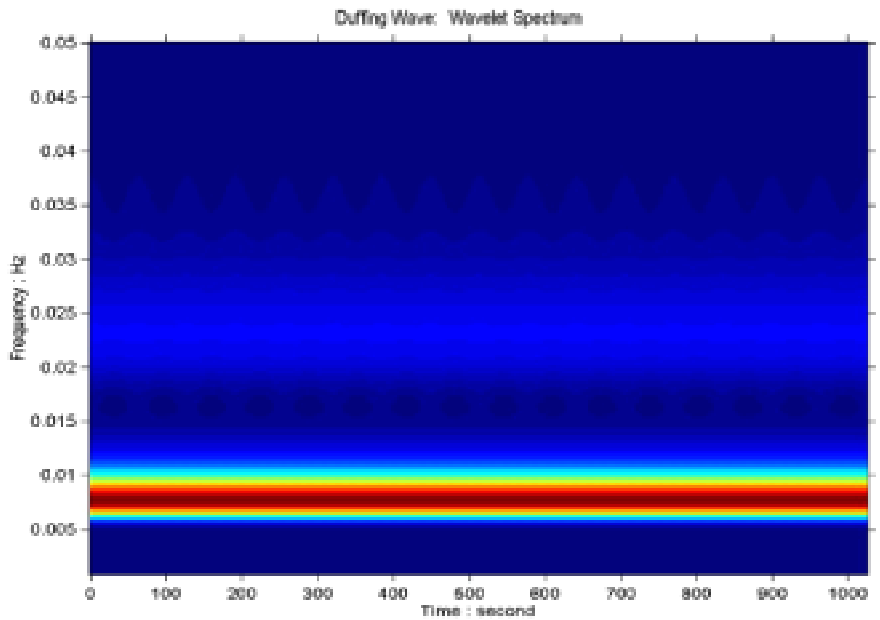
The EMD phase produces a set of IMFs that represent the original data vector broken down into frequency components from highest to lowest frequency. If all of the IMFs for a given signal are added together, the resulting "summation" signal is a near perfect match for the original signal. The difference between the original and "summation" signals is typically less than .001%, yielding a high level of confidence in the empirical results.

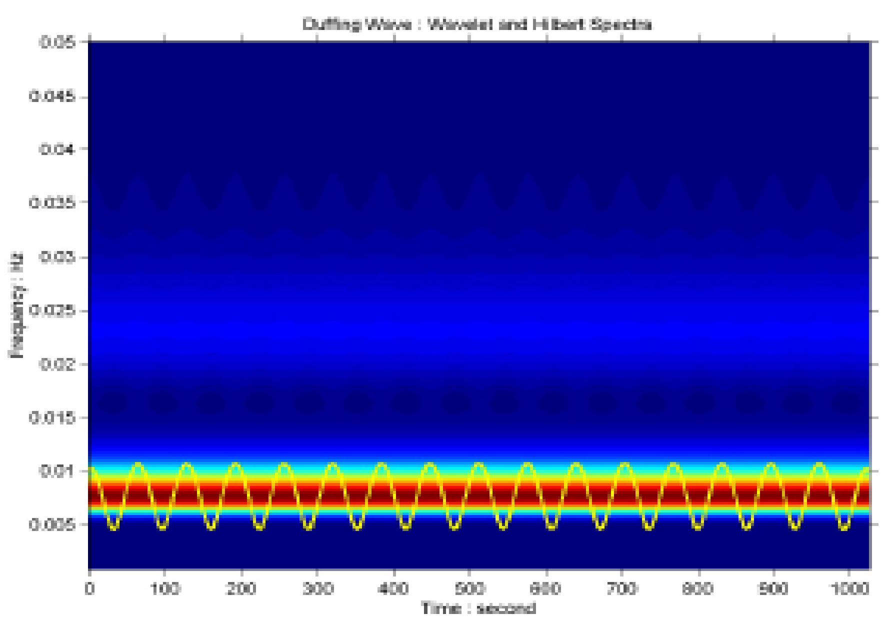
All IMFs are well-suited for the Hilbert Transform. The key advantage of using a Hilbert Transform, rather than FFT or wavelet processing, is that it allows the use of instantaneous frequency to display the data in a "time-frequency-energy" format. This produces a more accurate "real-life" representation of the data without any of the artifacts imposed by the non-locally-adaptive limitations of FFT or wavelet processing. The figure below shows a comparison of HHT, FFT, and wavelet output for a common input signal.



Hilbert processing highlights details that may be obscured with FFT and wavelet processing. When analyzing many "real-world" data sets the wavelet method spreads frequency energy, removing definition from the data and giving it an overly smooth appearance. The following figures show the results of wavelet processing on a "real-world" data set, and the additional detail revealed by the Hilbert method.


Data : Duffing type wave
Amplitude
Time : second


Duffing Wave: Wavelet Spectrum
Frequency : Hz
Time : second


Duffing Wave : Wavelet and Hilbert Spectra
Frequency : Hz
Time : second

Discussion of Software Implementation

The NASA Goddard Space Flight Center has developed generic, low-cost, high-performance, PC-based software that implements the HHT computational algorithms in a user-friendly, file-driven environment. The Hilbert-Huang Transform Data Processing System (HHT-DPS) prototype is currently being tested using data provided by a number of scientific and engineering application teams, and the data analysts from the respective provider organizations will evaluate the results when testing is completed.

Dr. Huang's algorithms and patents were used as the starting point for the HHT-DPS, and a complete set of software functions was developed—first modeled in Matlab and then coded in ANSI C. The initial functional performance of the system was verified by comparing the HHT-DPS output to the output of Dr. Huang's "EMD0.EXE" laboratory demonstration software. Further enhancements were made through several iterations with Dr. Huang and the HHT-DPS development team. The current HHT-DPS Version 1 now represents the state of the art for the HHT processing method. NASA-funded work in the coming year will focus on running a series of simulations and benchmarks to measure system speed and identify processing bottlenecks. This information will be used to target specific functions for hardware acceleration. Computationally intensive routines will then be implemented as Field Programmable Gate Array (FPGA) and Digital Signal Processing (DSP) hardware functions and integrated into the baseline system to produce the final high-performance system.

The HHT-DPS Version 1 software is available for 60-day evaluation upon the execution of an appropriate Software Usage Agreement (SUA) with NASA.